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VARIABILITY OF NAL LINAC ENERGY

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A common impression exists that the energy of a linac is fixed or variable over a very limited range at best. This may be true for a one-cavity linac (and if one ignores the low energy tail of an energy spectrum resulting from imperfect acceleration of particles). For a linac divided into several cavities which are variable in rf phase relative to one another, it becomes possible in theory[1] to vary the output energy in a controlled fashion over a large energy range.

The 200-MeV proton linacs at NAL and BNL consist of nine cavities each. Each cavity after the first, which delivers 10 MeV, adds an increment ranging from approximately 17 to 29 MeV in normal operation. It is clear that energy steps of this magnitude can be obtained by just turning off or shifting in time the rf field in each cavity, one at a time. It is possible to reach intermediate energies by shifting the rf phase of the last operating cavity. The result is a synchrotron oscillation of the proton bunch about the synchronous energy and phase. The output energy is then increased or decreased depending on the amount of phase oscillation within the rf bucket that the proton bunch experiences in the last excited cavity. In addition, for the higher energy cavities, the beam can be carried along for some distance outside the normally stable bucket because of the slow rate of phase oscillation.

For normal operation as an injector to another accelerator, the linac is maintained at constant energy. The emphasis is placed on minimizing momentum spread, typically 0.2% for approximately 95% of the beam. This is accomplished by proper phasing of linac cavity number nine (the last cavity).

For use of the linac beam in cancer therapy, variation of the beam energy is desirable. As a check on the possibilities, a few hours were spent last November in collection of some data. Figure 1 shows variation of energy with rf phase of the last excited cavity, one curve for each cavity, #3 through #9. One sees that the maximum energy from one cavity overlaps with the minimum energy of the next except for a small gap between #4 and #5. The reason for this gap was a limit in the range of phase attainable at the time. The vertical bars indicate limits on phase variation, which can be easily extended by simple changes of coaxial cable lengths.

The data for each curve were obtained by allowing the beam to drift through the remainder of the linac to a spectrometer magnet in the 200-MeV diagnostic area. There was some loss of beam through the spectrometer for part of curve 3 because of increased energy spread and improper setting of the transport magnets at this low energy. In practice, one would need to change the phase of more than one cavity at the same time to minimize the energy spread as the output energy is varied.

[1] K. Batchelor, J. Bittner, R. Chasman, N. Fewell, T. Sluyters, and R. Witkover; Beam Performance of the 10-MeV Section of the 200-MeV Linear Accelerator at Brookhaven National Laboratory, Proc. of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, p. 185

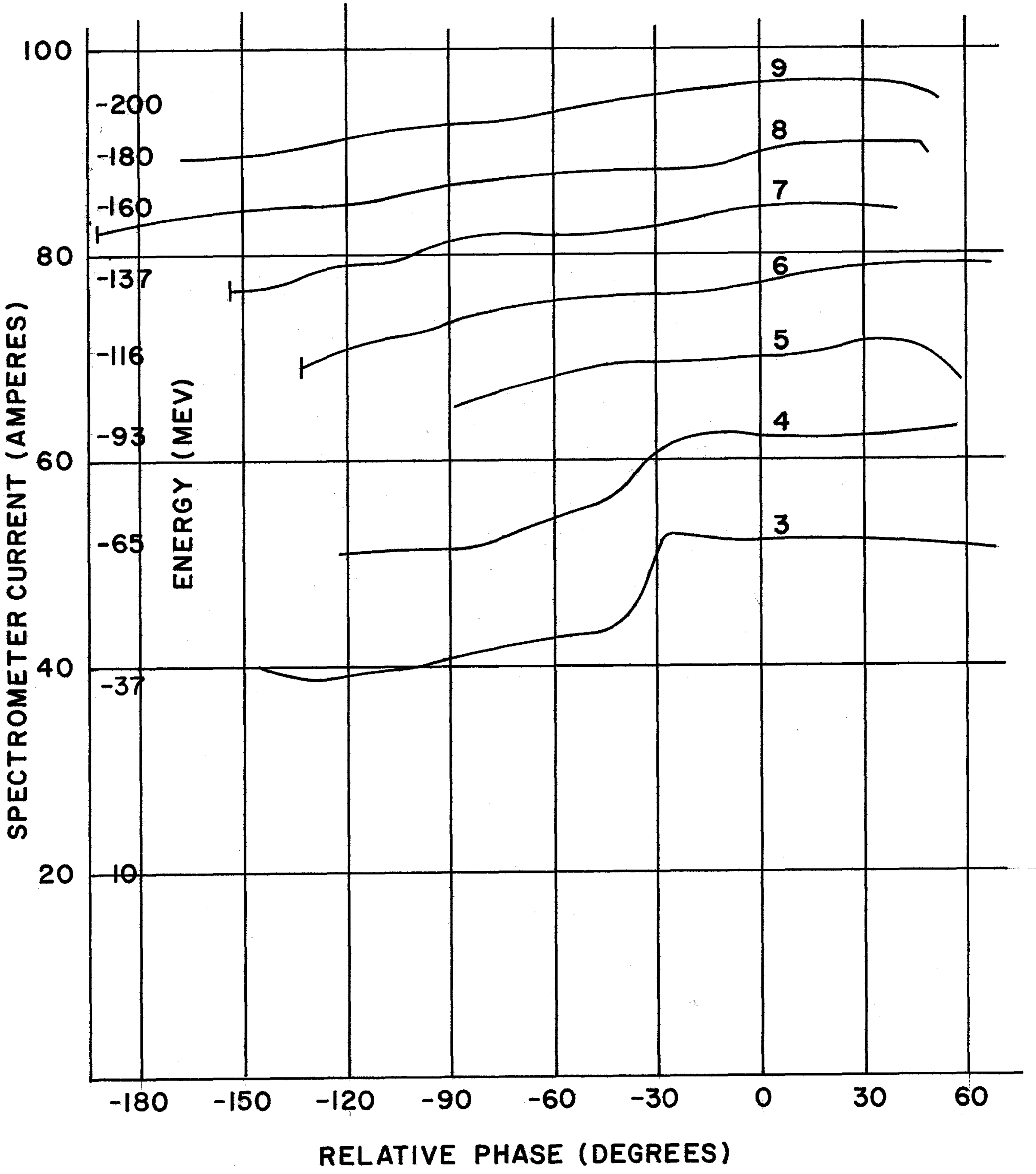

Fig. 1. Variation of Linac Beam Energy